Mixing by Tidal Interaction with Sloping Boundaries

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LONG-TERM GOALS

The long-term goals of this project are to obtain an understanding of the mechanisms by which tidal energy is used to vertically mix the ocean against the action of gravity. Ultimately better parameterizations of the mixing caused by tides will result, allowing better prediction of coastal dynamics, biogeochemistry and sediment transport and the oceanic general circulation.

OBJECTIVES

The process of mixing by tides interacting with topography involves several stages. First some fraction of the energy contained in the barotropic tide must be converted into baroclinic energy, through the generation of internal tides and turbulent boundary layers. Secondly, the energy in the internal tides must be transmitted into smaller vertical wavelengths, thereby increasing the vertical shear of the motion. When vertical shears are sufficiently strong, instability may result, leading to overturning and mixing. Finally, the mixed fluid is transported away from the mixing region modifying the ocean stratification. The net effect of the tides on the ocean stratification depends on the efficiency of all three processes.

Our objectives are to understand (a) the generation of internal tides by the interaction between barotropic tides and topography including finite-amplitude 3-dimensional variations in topography, finite-amplitude barotropic tidal forcing, non-hydrostatic effects and the boundary layer processes; (b) the mixing generated by internal tides reflecting from a sloping boundary in the presence of both 2 and 3-dimensional variations in slope, and finite rotation; and (c) the mechanisms of lateral and isopycnal transport of mixed fluid away from the boundary induced by the secondary circulations generated through spatial variations in mixing. Earlier studies have ignored 3-dimensional large amplitude variations in topography and non-hydrostatic effects (which are important for small-aspect ratio motion).

APPROACH

We use high-resolution numerical simulations to explicitly resolve the turbulent mixing processes. For such simulations we require a numerical model which can (a) capture the non-hydrostatic physics of overturning and mixing processes (b) include arbitrary 3-dimensional variations in topography. The Marshall et al, (1997a,b) code (known as the MIT ocean model), which is non-hydrostatic, and includes topography through a finite-volume formulation, is such a model.

We will carry out 3 different groups of simulations: (a) We will impose topography, barotropic tides and subinertial flows suggested by recent observations (e.g. Norfolk canyon region: Polzin et al, (1998), and Monterey Canyon region, Petruncio et al, 1998), and investigate the internal tide generated by the flow-topography interactions, comparing these results with earlier models which assume small-amplitude (e.g. Bell, 1975) or 2-dimensional finite amplitude (Baines, 1982) topography.(b) We will impose internal tide forcing and investigate the interaction with a 2-dimensionally varying slope, focusing on the influence of finite rotation on the overturning and mixing, and the effect of slope variations in localizing mixing, comparing with earlier laboratory and numerical studies with uniform slope and no rotation (Ivey and Nokes, 1989; Slinn and Riley, 1996). (c) We will impose internal tide forcing and investigate the interaction with 3-dimensional topography variations, focusing on the localization of mixing, and the resultant secondary circulation and lateral transports of mixed fluid.

WORK COMPLETED

In the past year we have focused on the internal tide generation problem, working closely with Kurt Polzin to compare results with observations from the TWIST region. We have carried out the following series of simulations.

Data from the LIWI funded TWIST project (Kurt Polzin, PI) have been used to initialize the stratification and topography for a region of the East Coast. We force the model with the barotropic tidal signal at the open boundary and investigate the internal wave response as the barotropic tidal signal encounters the continental shelf. Topographic variations such as canyons and ridges are included, and the 3-dimensional response of the flow simulated.

In more idealized domains, the generation of internal tides at the continental slope and shelf break have been simulated, with the focus on the influence of slope variations in the cross-shelf direction. Internal tide energy flux has been compared with predictions from linear models (e.g. Baines, 1982).

RESULTS

1. Tidal mixing in canyons in the TWIST region

Cross-slope barotropic tides interacting with corrugated topography consisting of canyons and ridges running across the continental slope generate strong shears in the canyons. If the shears are sufficiently strong that the Richardson number is less than 1/4, shear instability results, and mixing occurs, confined to the canyons (Figure 1). This mixing is completely absent if the topography has no along-slope variations, when flows near the topography are small away from the shelf-break. Observed velocity profiles contain more vertical structure than in the simulations, and hence greater complexity is required to fully explain the observations, including probably the along-slope tide and subinertial current interactions with the topography, and perhaps remotely generated internal waves reflecting from the topography. These possibilities will be pursued in the next year.

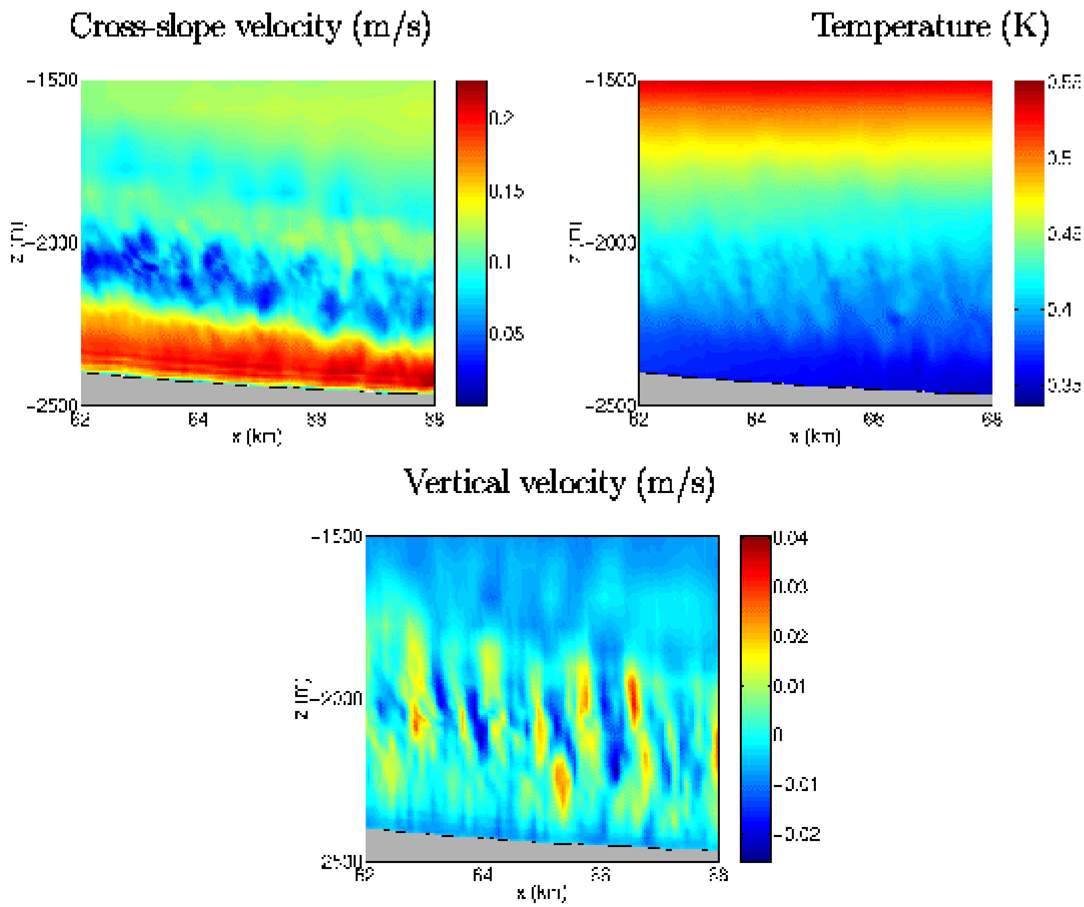

Figure 1: Close-ups of cross-slope velocity, temperature and vertical velocity in a canyon. The barotropic tidal forcing has led to the generation of a sheared flow in the canyon, as flow is deflected around the ridges. For the forcing amplitude imposed (30cm/s), the shear in the canyons is sufficiently large to reduce the Richardson number below 1/4. Shear instability results with associated up and down welling (seen in the vertical velocity field). Filaments of dense fluid are mixed with lighter fluid above (seen in the temperature field).

2. Conversion of baroclinic energy into the internal tide

A series of simulations has been performed examining the interaction between cross-slope barotropic tide with a continental slope which is uniform in the along-slope direction. The different simulations are distinguished by different slopes, including concave, convex slopes and planar slopes at the critical slope and steeper than the critical slope (supercritical). Uniform stratification is used to enable comparison with the analytical theory of Baines (1982). The internal wave energy flux is found to depend strongly on the slope (Figure 2), with steep slopes just below the shelf break leading to the largest energy flux (e.g. the supercritical slope and the concave slope). The energy flux for the steep slope is of the same order of magnitude as for the linear prediction, although smaller. Mixing and overturning at the shelf break, absent from the linear model, but present in the simulations are likely the cause of the discrepancy.

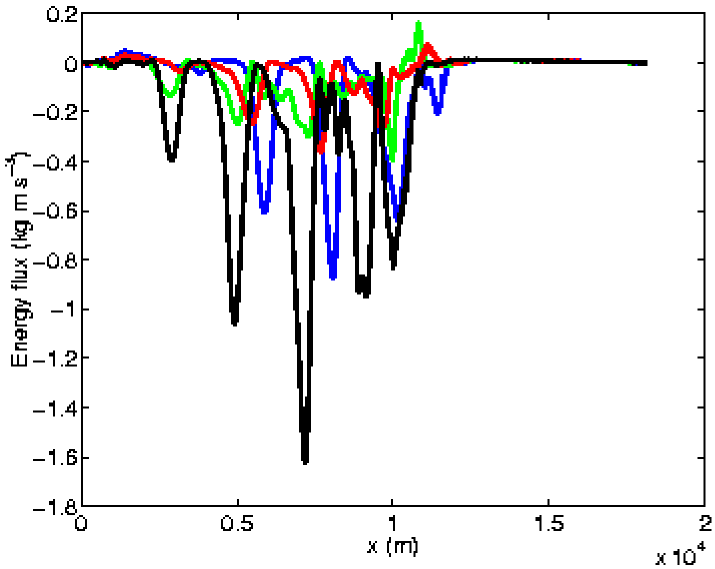

Figure 2: The instantaneous internal wave energy flux E = ∫ P'u' dz as a function of cross-slope distance, for 4 different simulations. A barotropic tide at the M2 frequency is forced at the left boundary (x=0). The topography consists of a flat bottom at a depth of 200m up to x=10km, followed by a slope and then a flat shelf at a depth of 40m. The slope varies between the different simulations: (i) planar slope at the critical angle (red), (ii) supercritical planar slope (black) (iii) convex slope with midpoint at the critical angle (green), (iv) concave slope with the midpoint at the critical angle (blue). The supercritical slope leads to the largest internal wave energy flux, followed by the concave slope, then convex slope and finally critical slope.

IMPACT/APPLICATIONS

Our results should help the interpretations of observations of tidally forced flows on the continental slope observed by LIWI investigators and others. We anticipate our results will eventually allow better parameterizations of tidal mixing to be developed, allowing better prediction of coastal dynamics, biogeochemical processes and the oceanic general circulation (Munk and Wunsch, 1998).

TRANSITIONS

We are communicating our results to other members of LIWI, K. Polzin, R-C Lien, and others, to help interpret their observations.

RELATED PROJECTS

This project examines processes closely related to observations included in LIWI (Polzin, Toole and Schmitt and Paduan, Rosenfeld, Kunze and Gregg). The work is related to the NSF-supported general circulation studies of Wunsch.

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PUBLICATIONS